SALT II

Steered Agile Laser Transceiver

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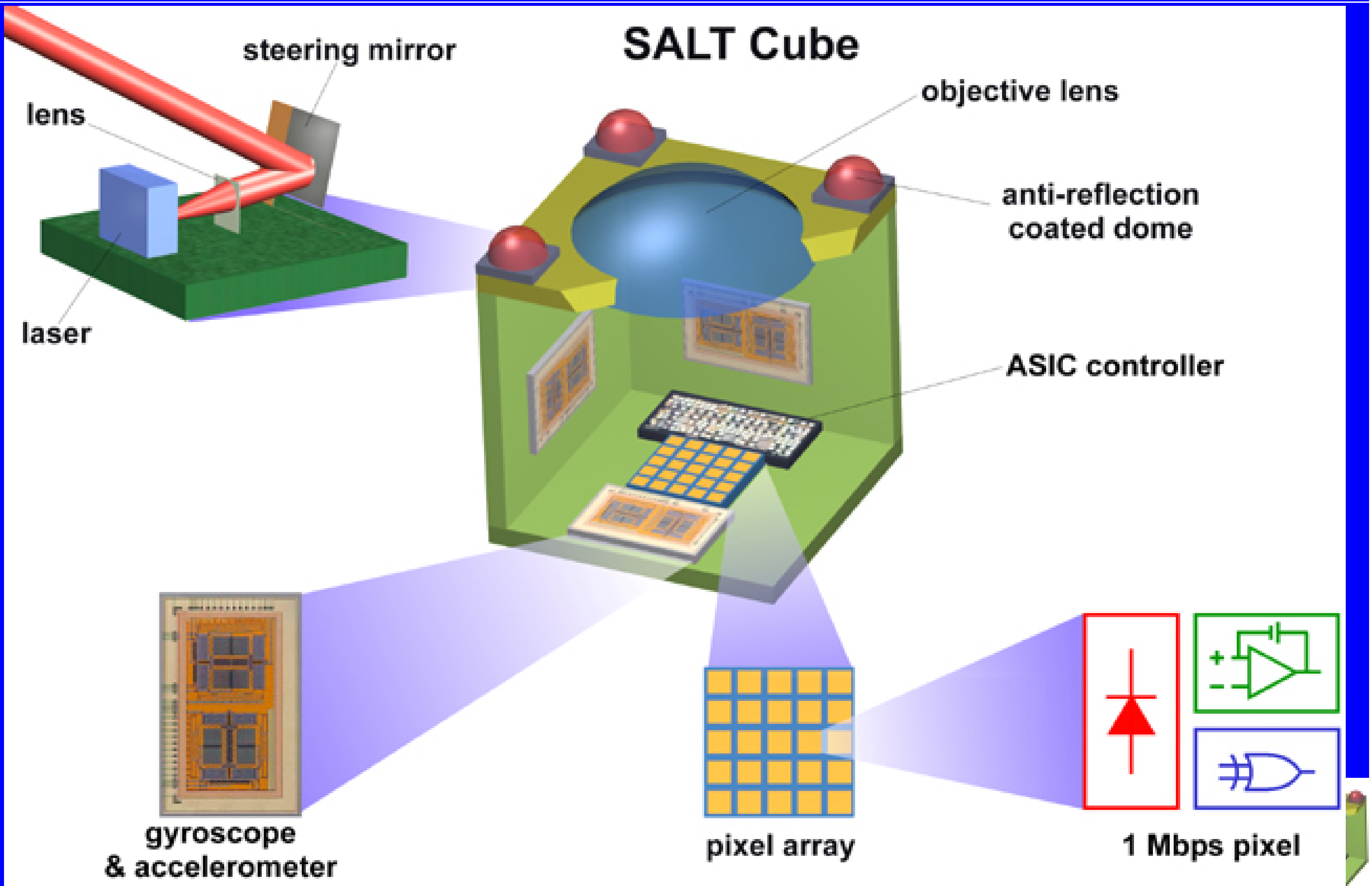
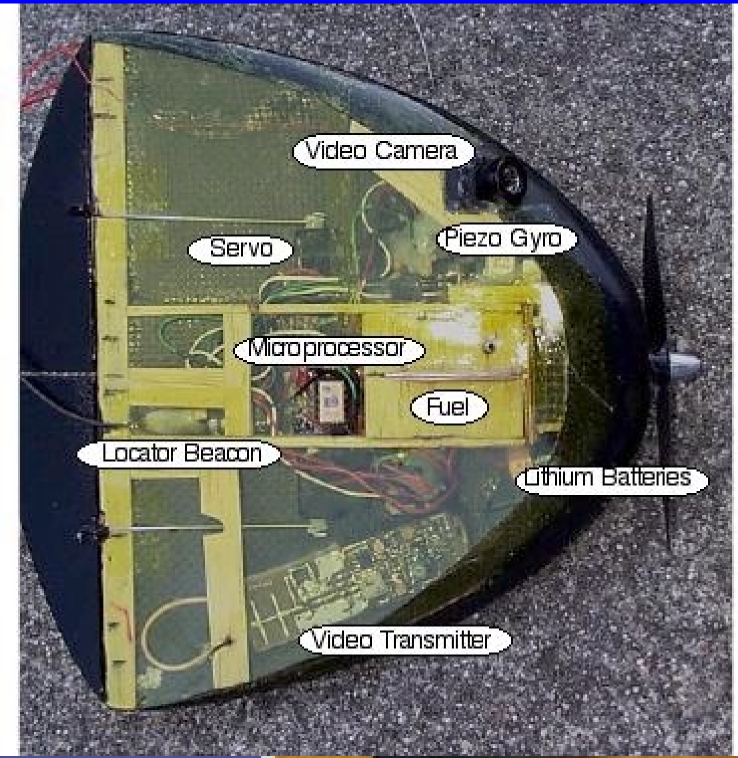
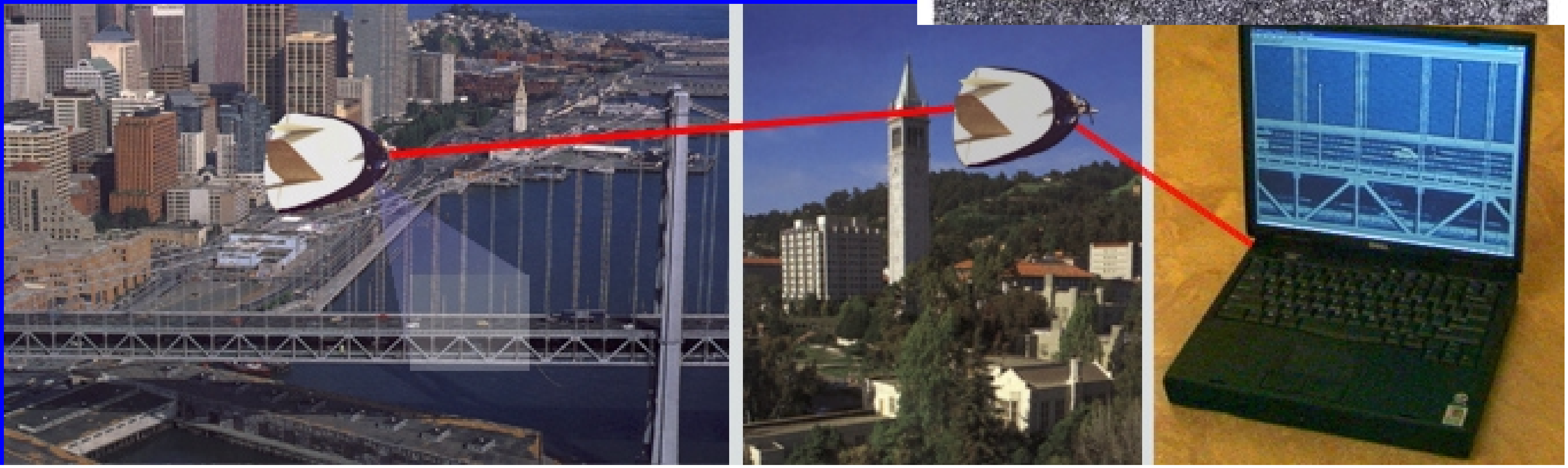
Goal:10 Mbps; 10 km; 1 cm^3



System Goal

- 10 Mbps
- 10 km
- 1 cm^3
- MAV to MAV comm
  - Problem: no MAV money





System Components

- Steered laser transmitters
  - COTS laser diode
  - MEMS variable focus lens
  - MEMS steering mirror
- CMOS imaging receiver
- 3 axis gyros and accelerometers
- Algorithms and software

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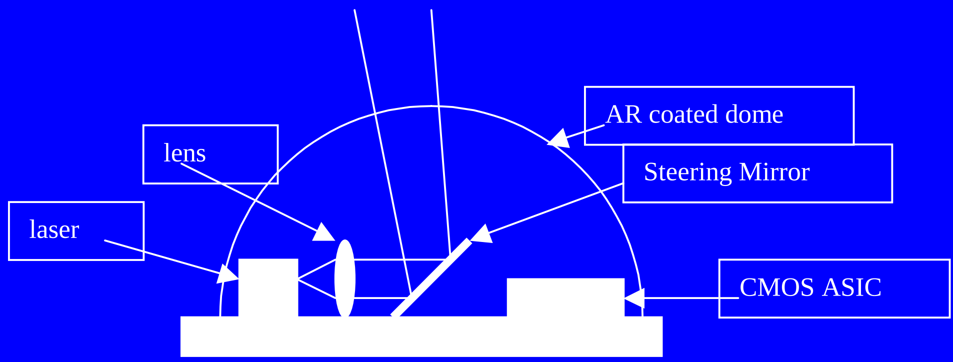
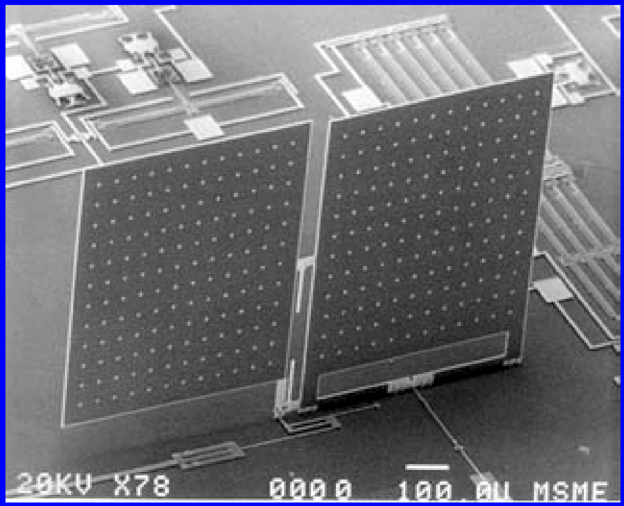
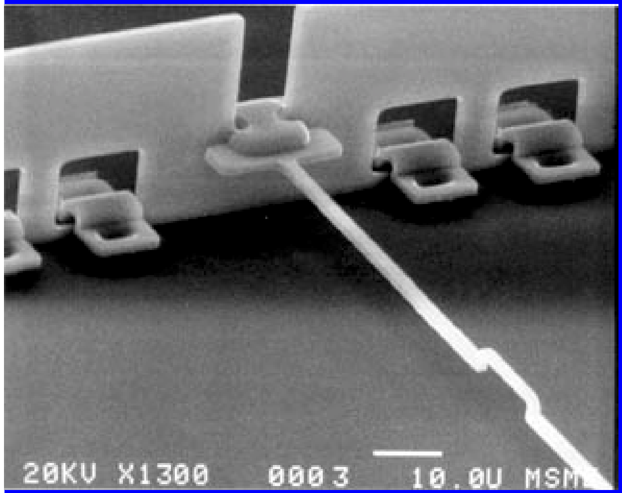
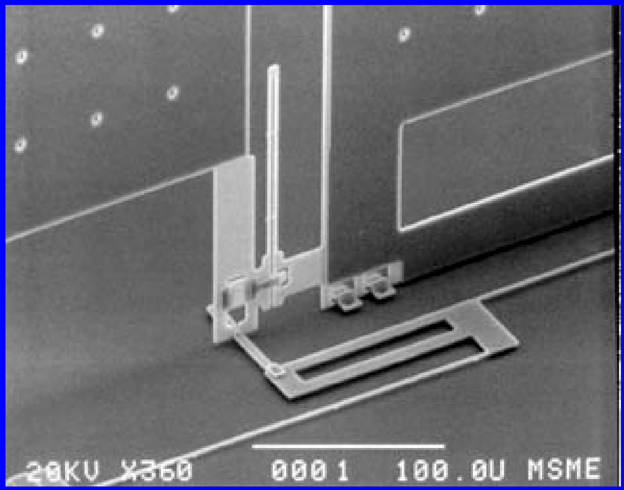
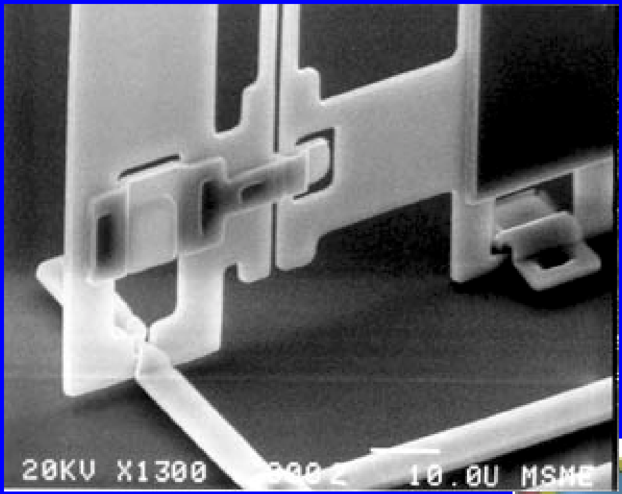
2D beam scanning



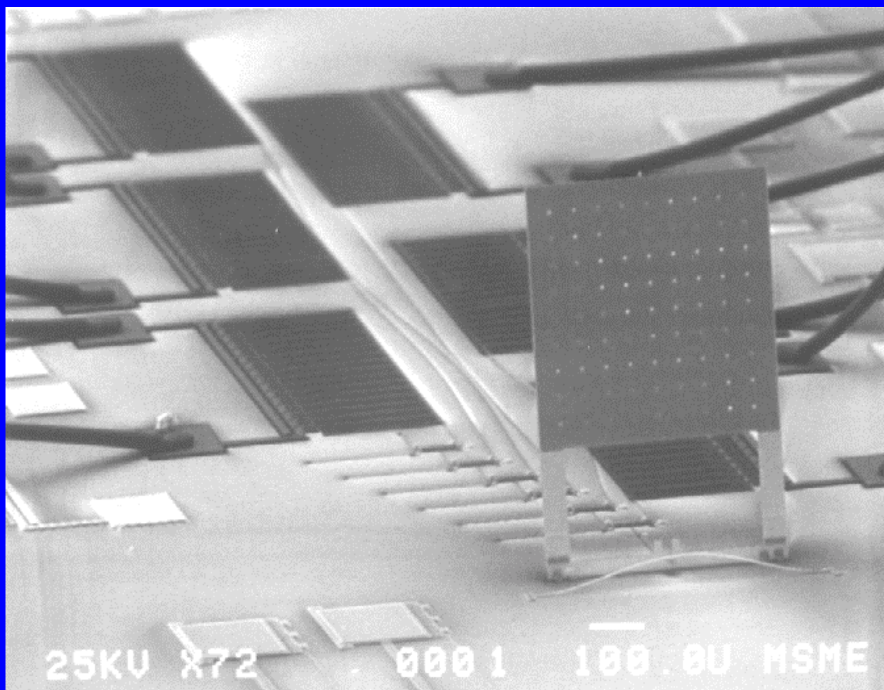


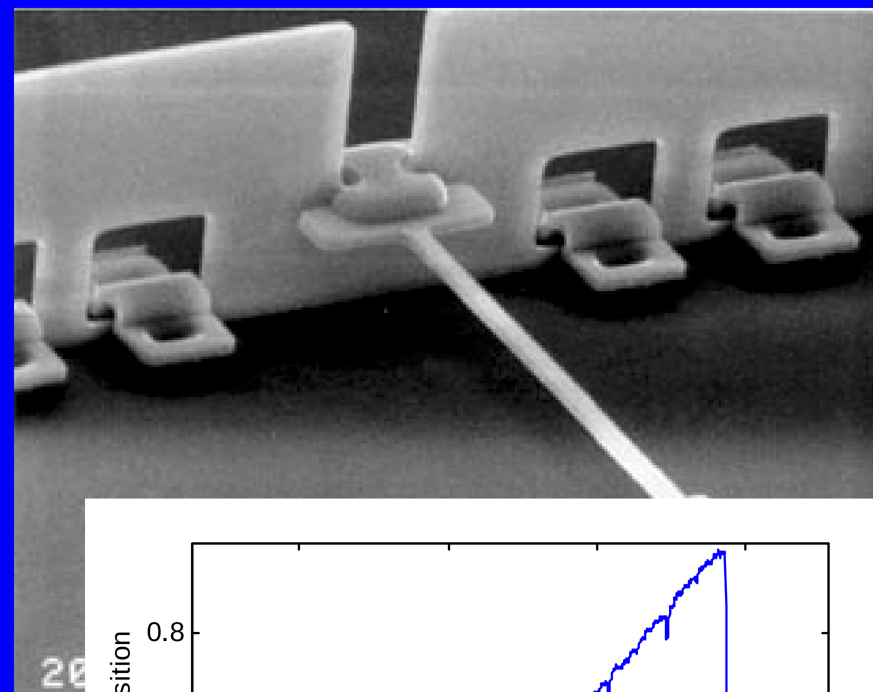


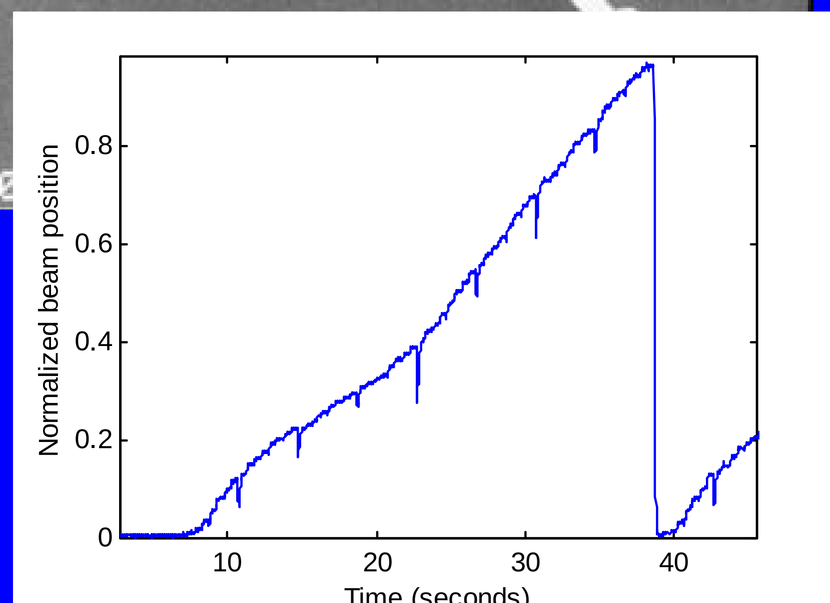




6-bit DAC Driving Scanning Mirror





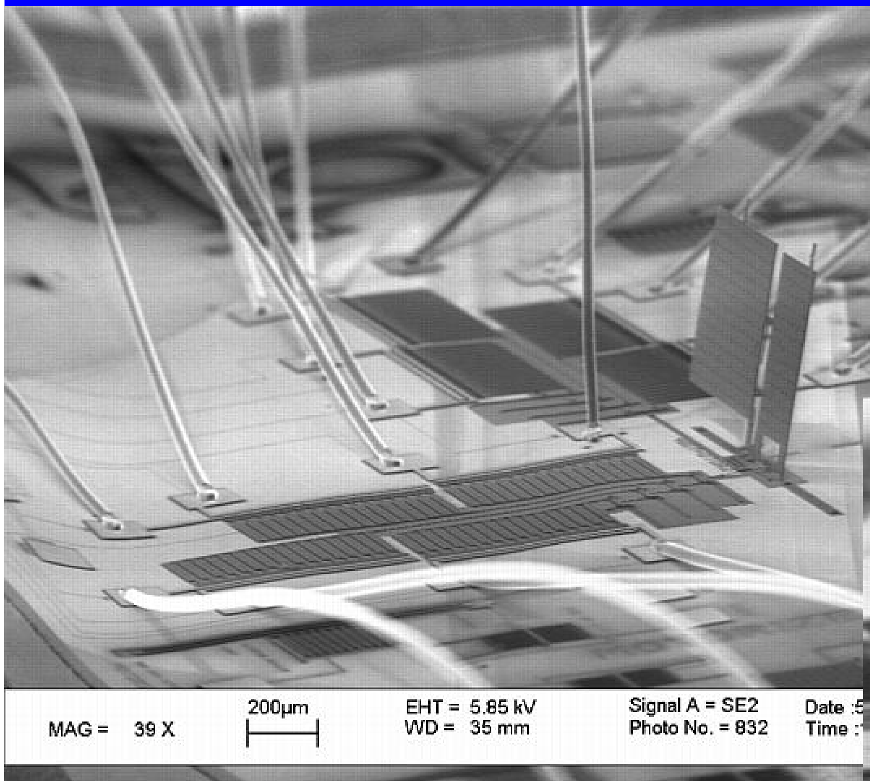


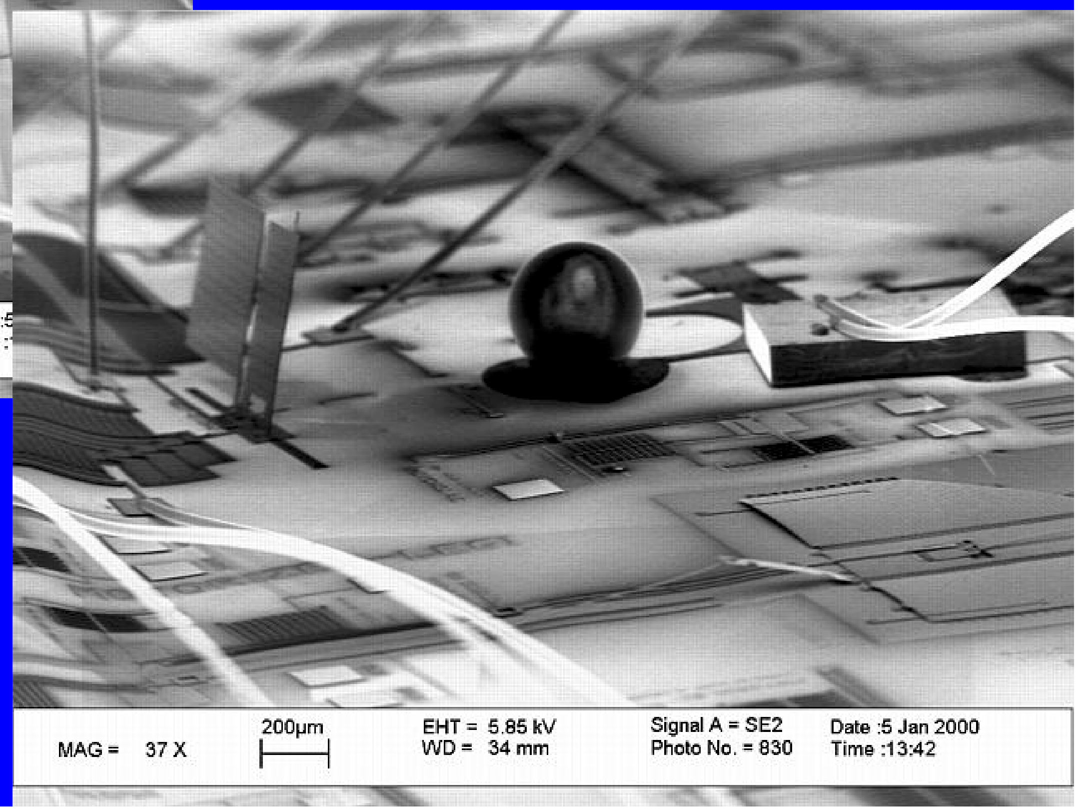
- Open loop control
- Insensitive to disturbance
- Potentially low power

~8mm^3 laser scanner

Two 4-bit mechanical DACs control mirror scan angles.

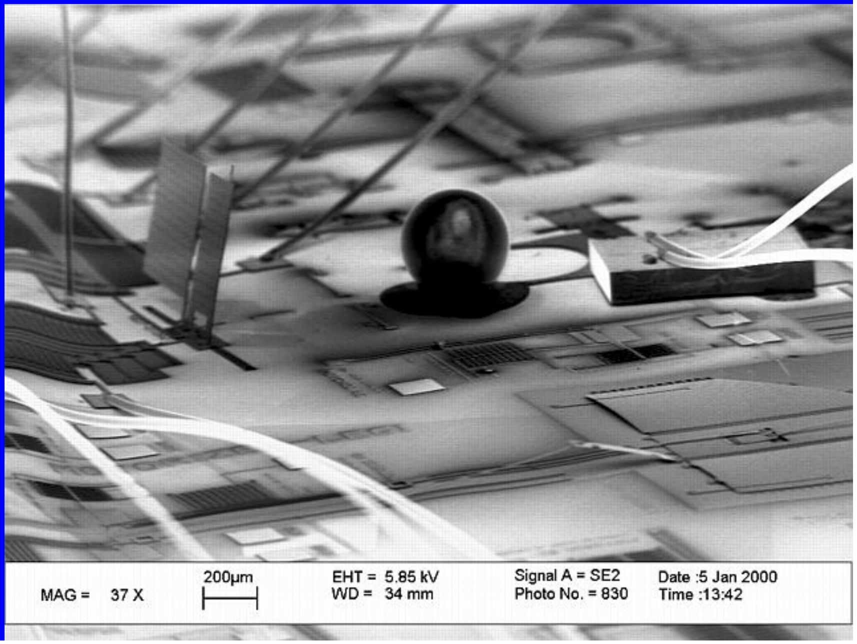
~6 degrees azimuth, 3 elevation



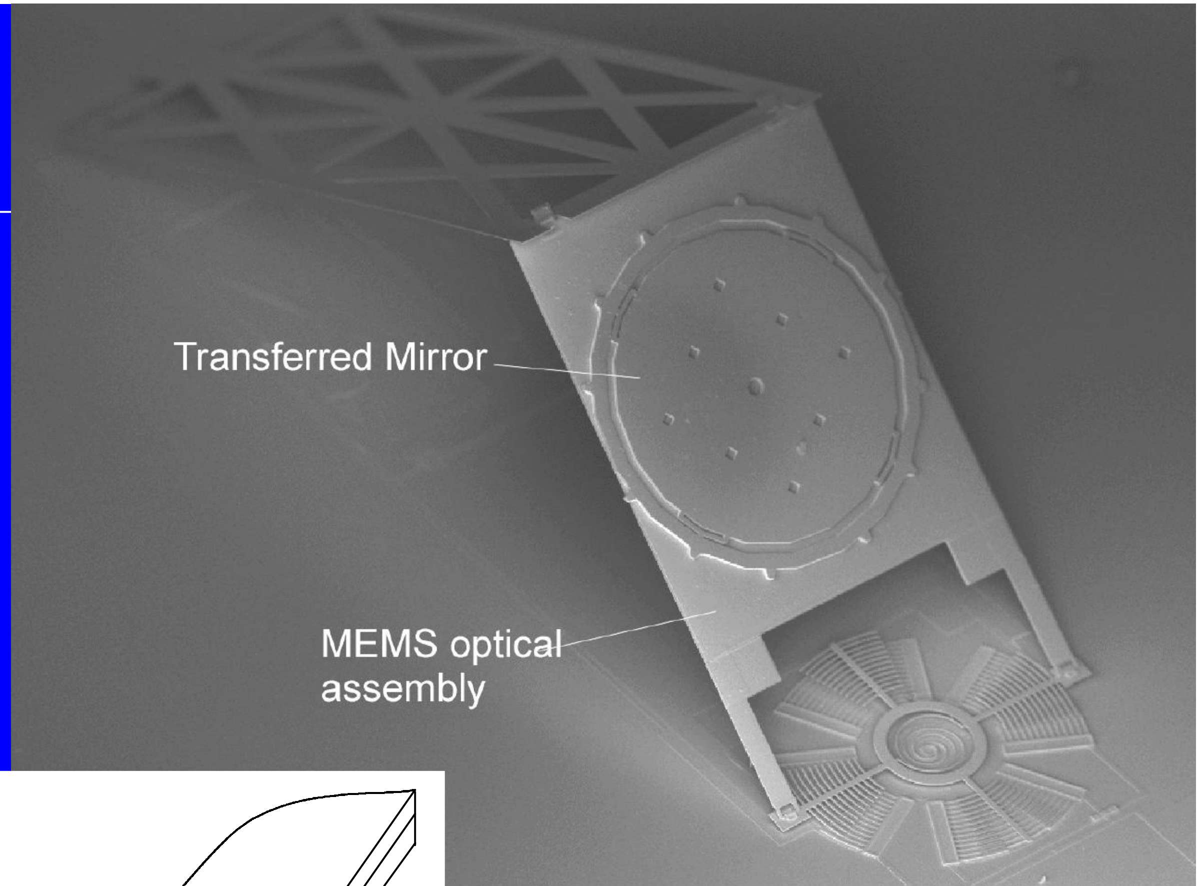


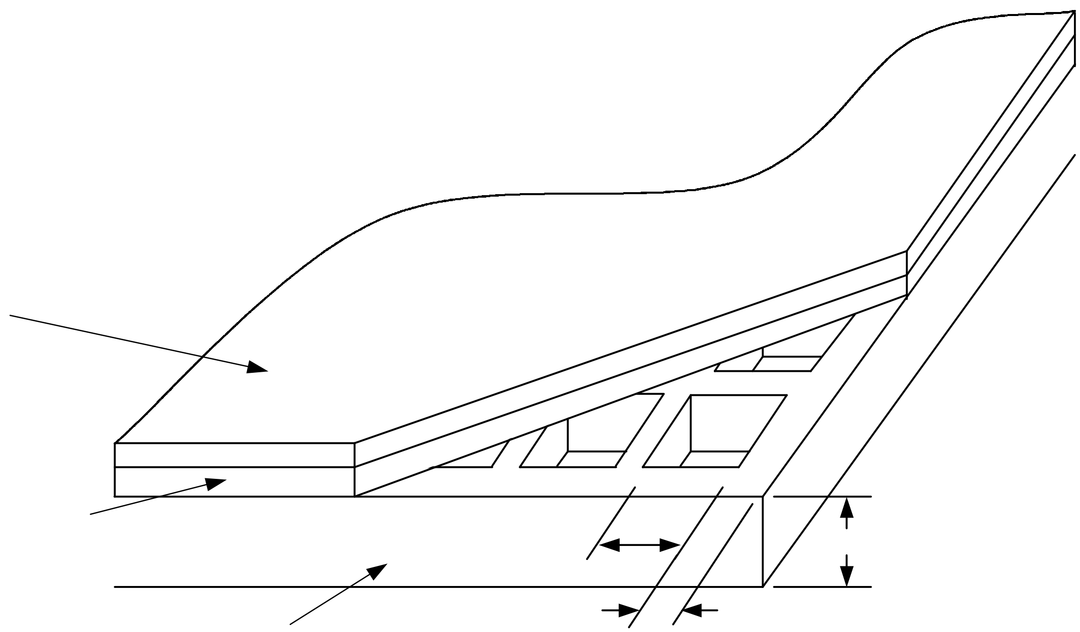
Steered Laser Transmitter (SALT I)

- 1Mbps demonstrated
- Not so agile (several milliseconds)
- Not much steering (several degrees)
- Bad alignment, huge divergence (degrees)
- $8mm^3$



Low inertia Mirrors





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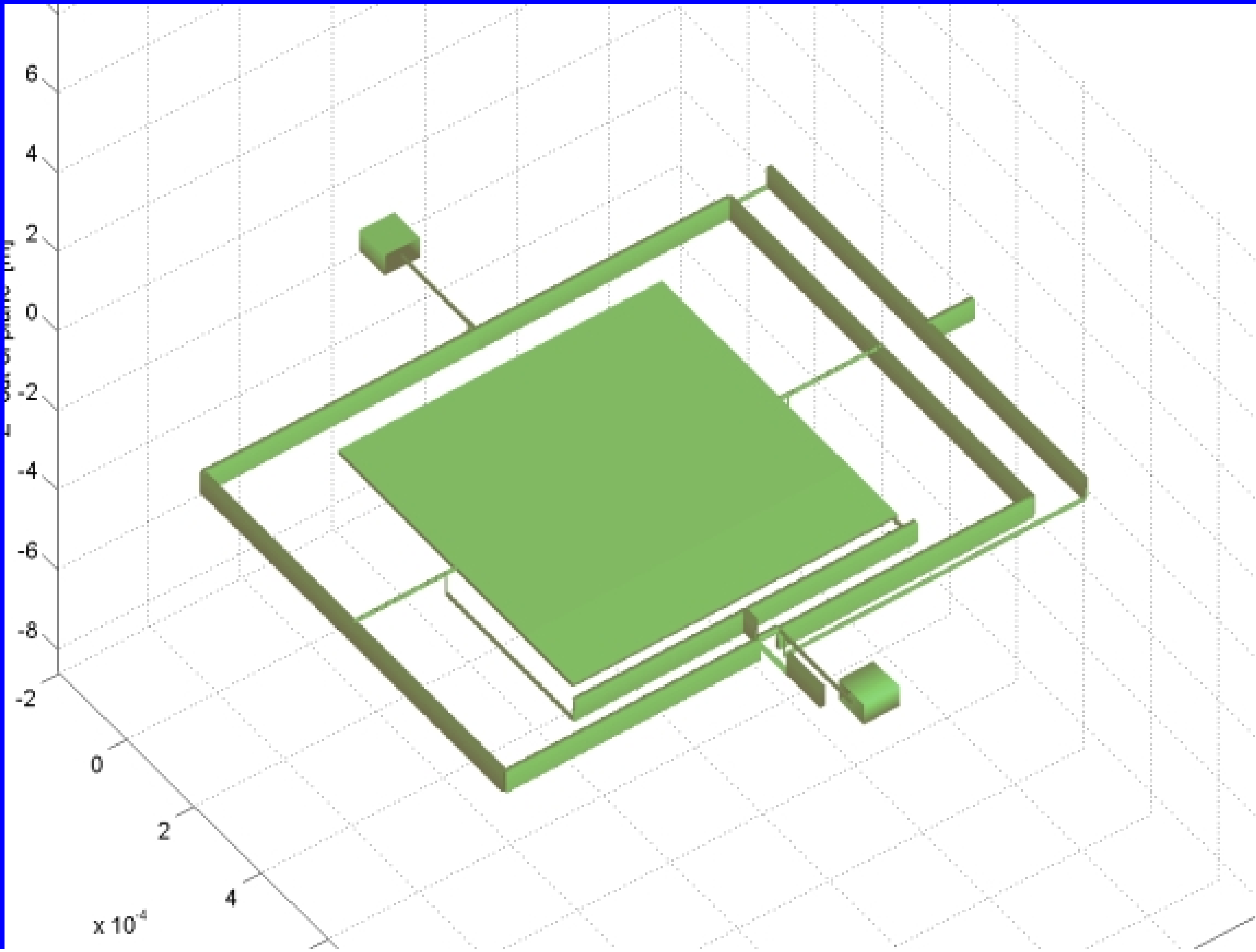
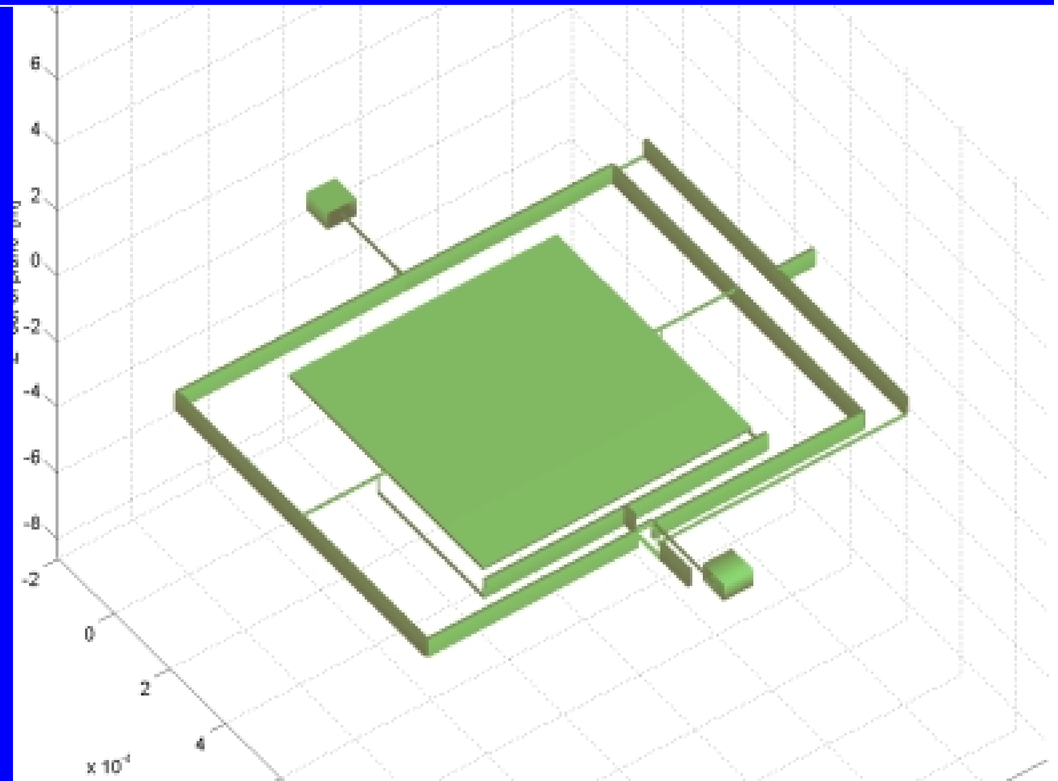
Laterally Actuated Gimbals

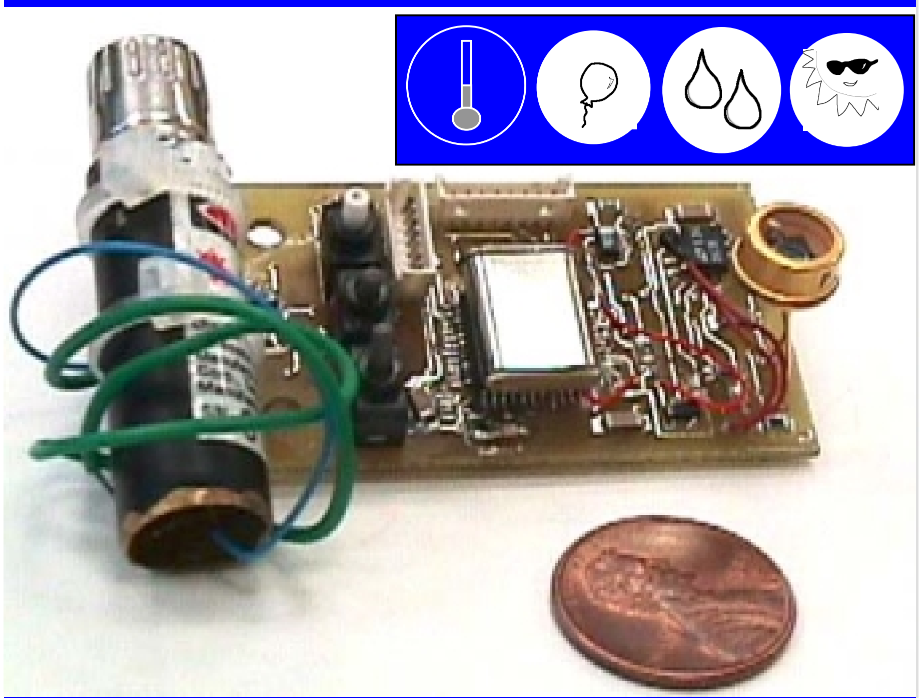


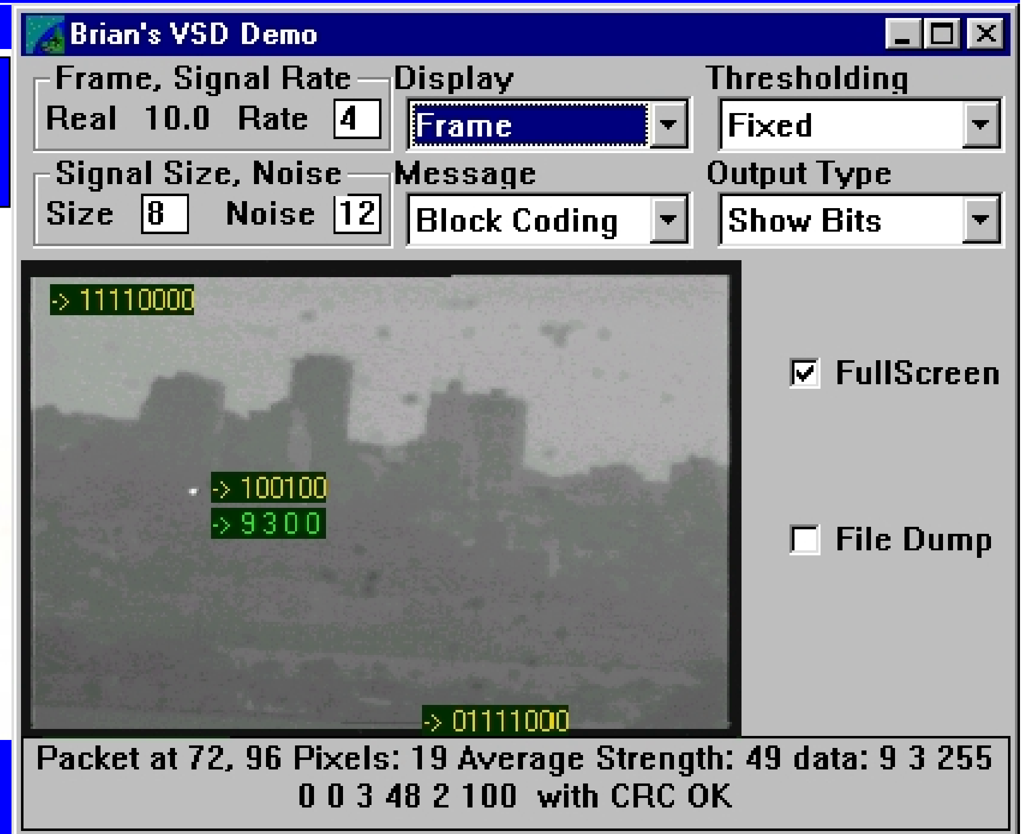
Laterally Actuated Gimbals



- Single crystal silicon
- Low inertia mirrors
- Scaleable
  - Mirrors
  - actuators
- Position sensing
- Large angle scanning
- Fast!
  - 700 micron mirror → 10 microsecond settling

COTS Optical Comm.





Laser mote

- 4bps OOK
- Laser pointer

CCD camera + laptop

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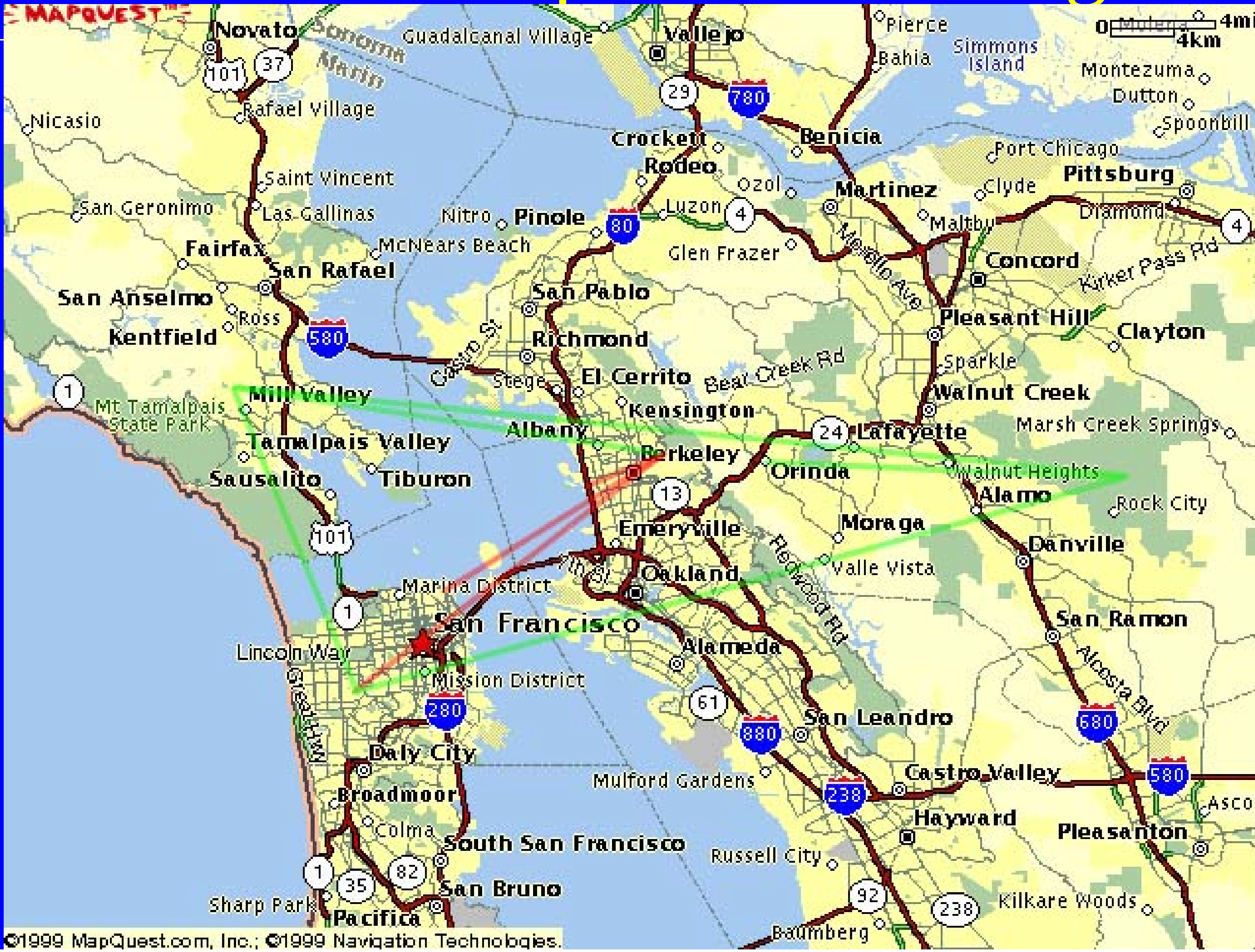
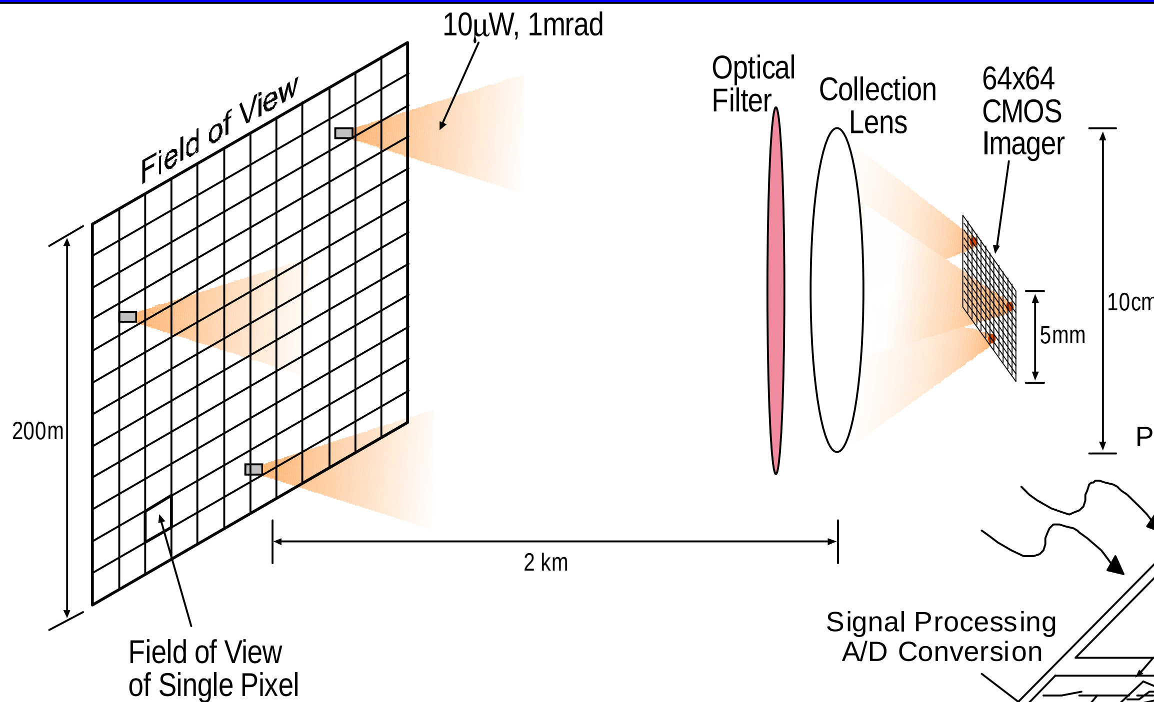
Video Semaphore Decoding

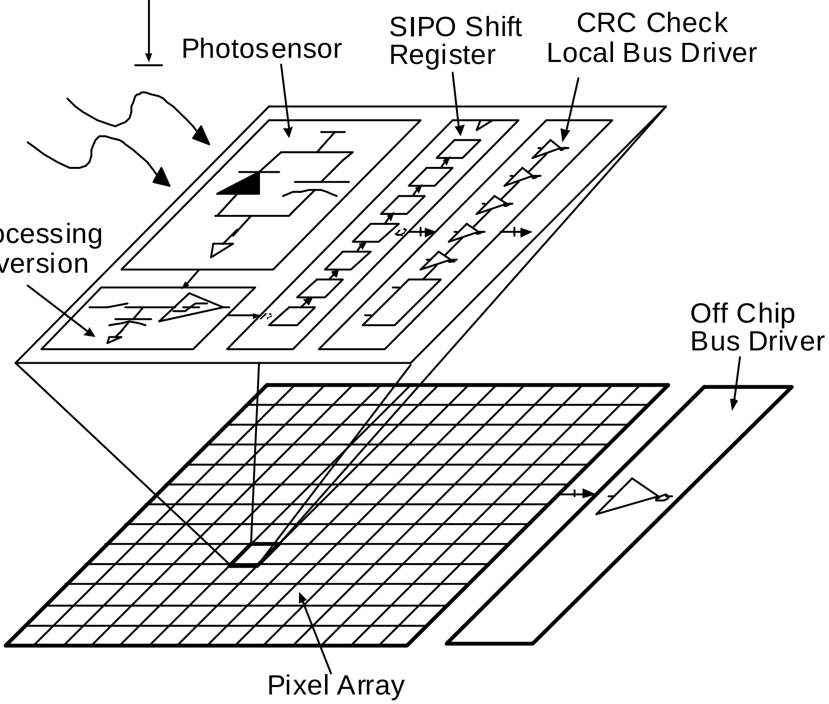


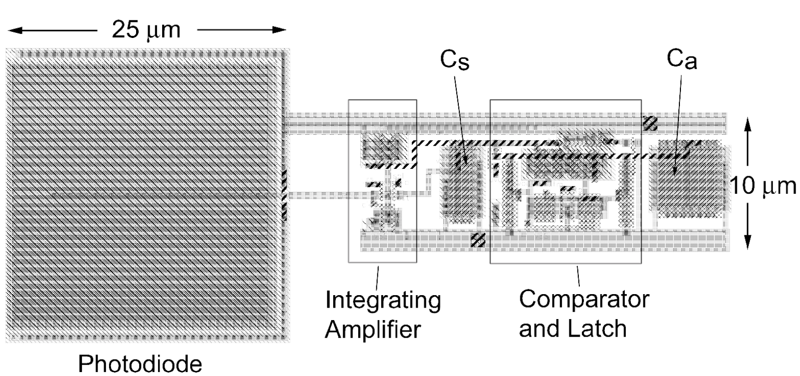
CMOS Imaging Receiver

- Array of pixels provides
  - Spatial division multiplexing
  - Reduced DC ambient
- CMOS Active Pixels
  - CON: limits wavelengths (<1000nm)
  - PRO
    - Cheap!
    - Easy/fast prototypes
    - Gordon Moore

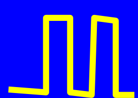
1 Mbps CMOS imaging receiver

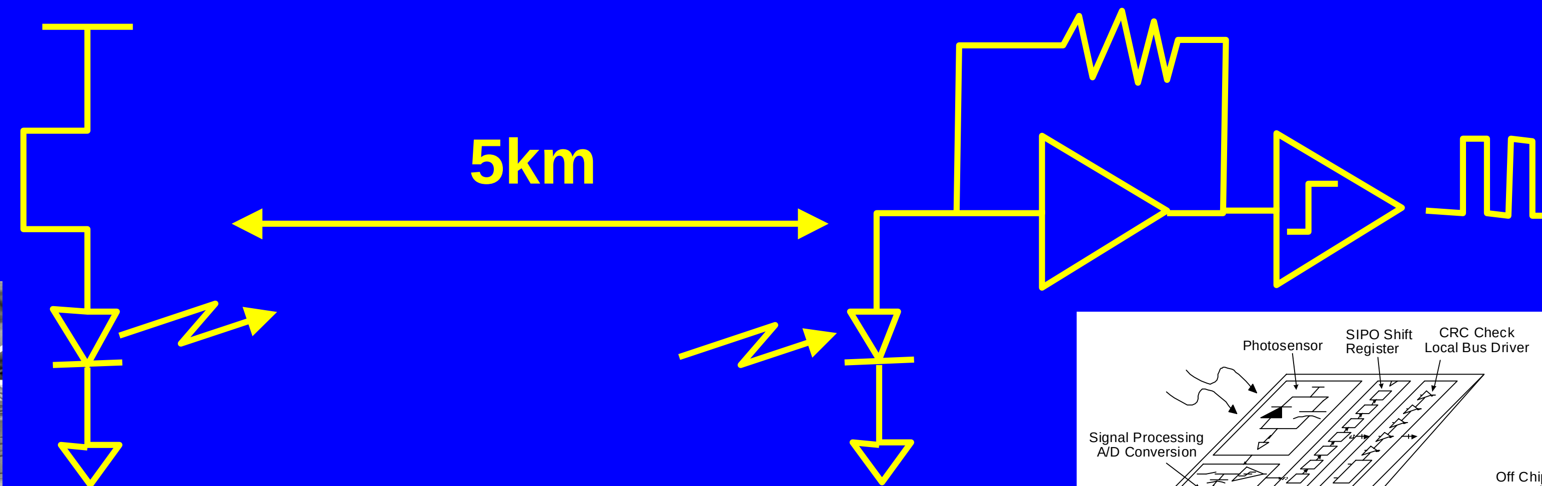


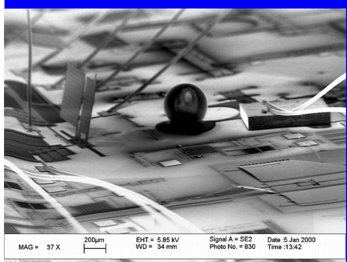


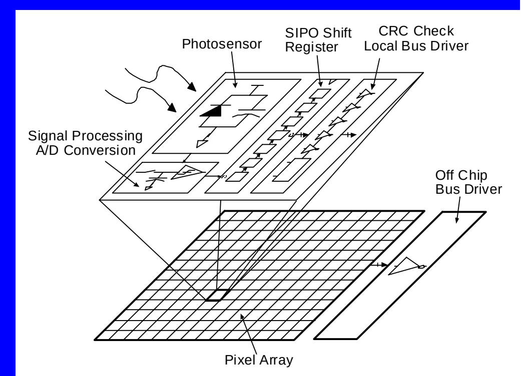


Theoretical Performance









P_{total} = 50mW
P_t = 5mW
$\theta_{½}$ = 1mrad → G_{ant} = 71dB
BR = 5 Mbps

10nJ/bit

$A_{receiver}$ = 1cm^2
P_r = 10nW (-50dBm)
P_{total} = 50uW /pixel
SNR = 15 dB
~10,000 photons/bit

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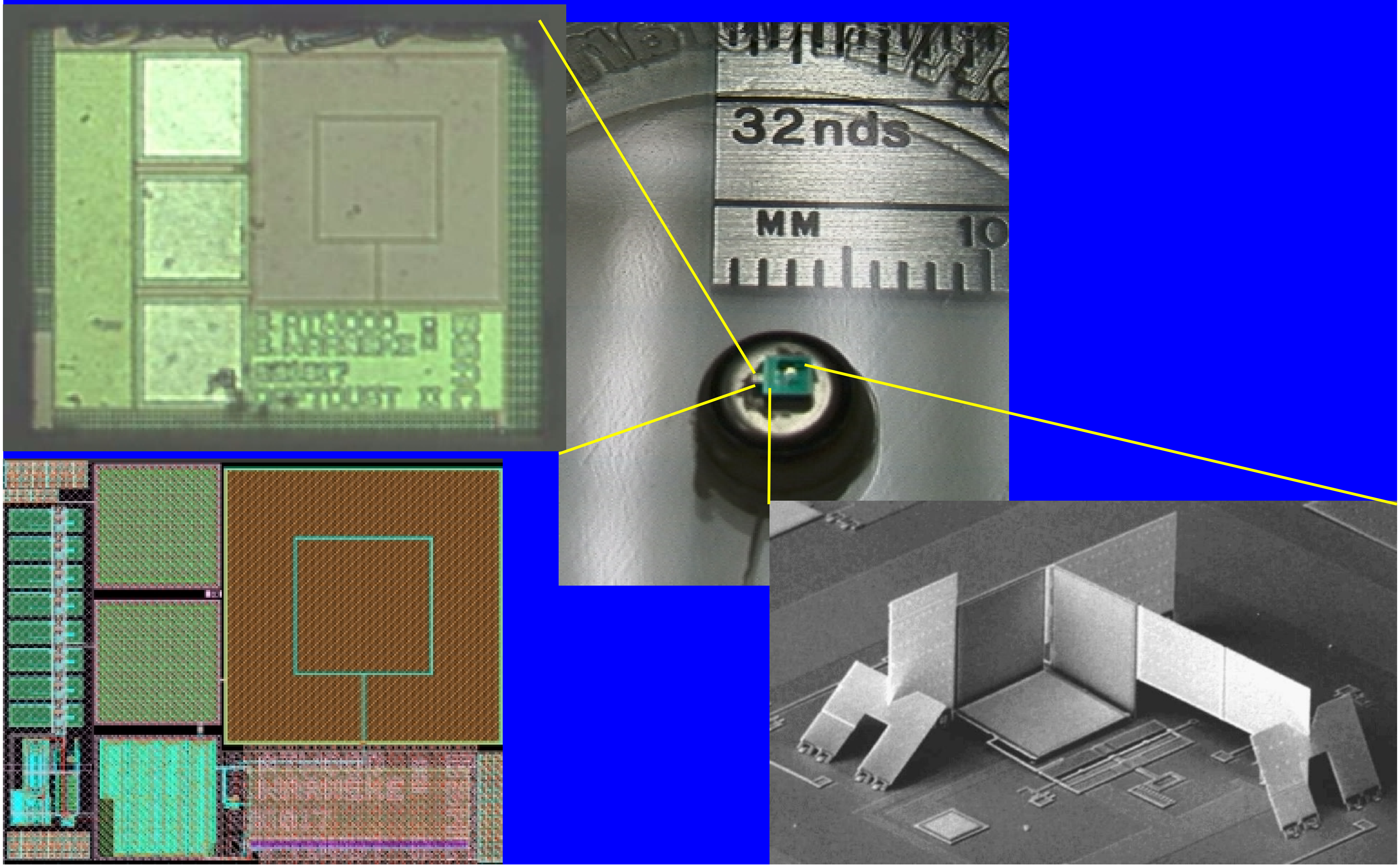
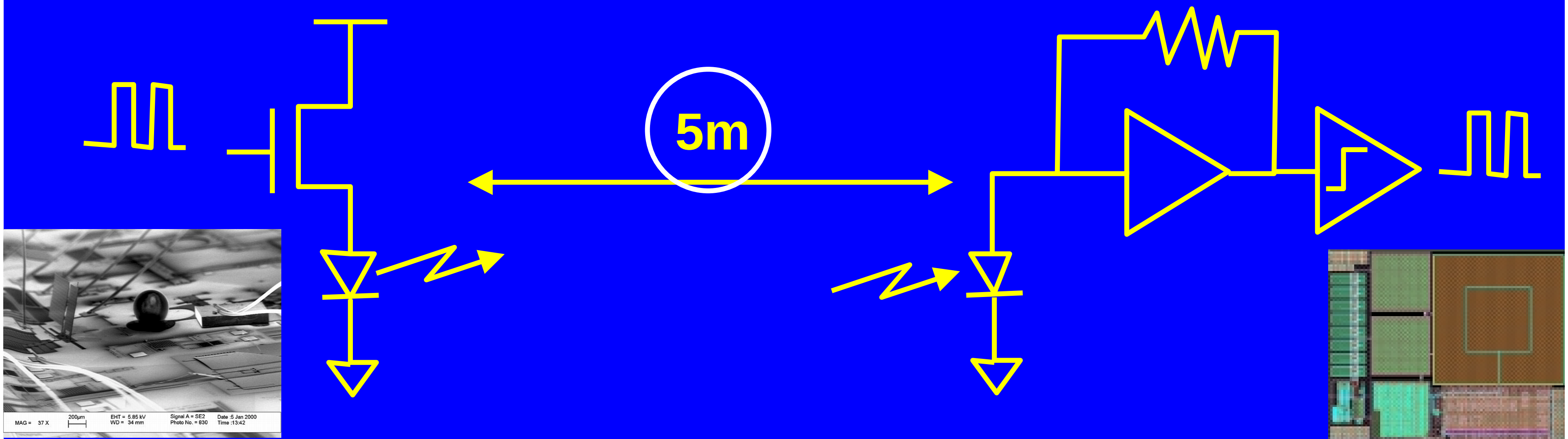
Smart Dust Mini Mote



Theoretical Performance

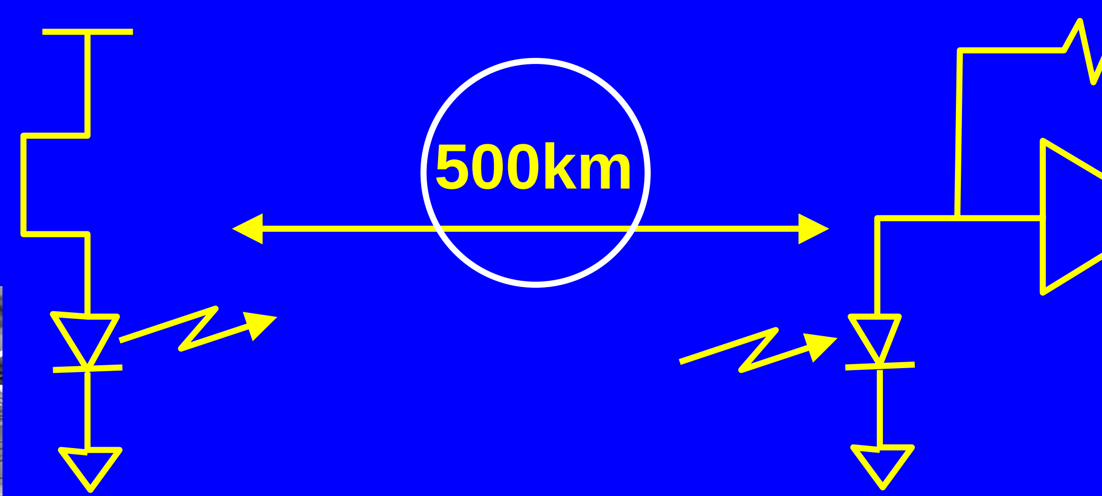


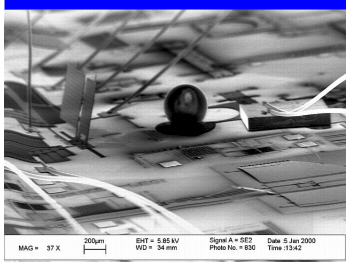
P_{total} = 100uW
P_t = 10uW
$\theta_{½}$ = 1mrad
BR = 5 Mbps

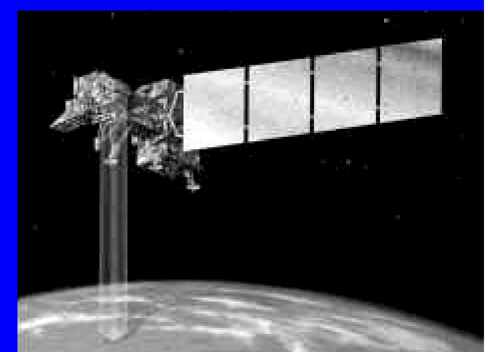
20pJ/bit!

$A_{receiver}$ = 0.1mm^2
P_r = 10nW (-50dBm)
P_{total} = 50uW
SNR = 15 dB

Theoretical Performance







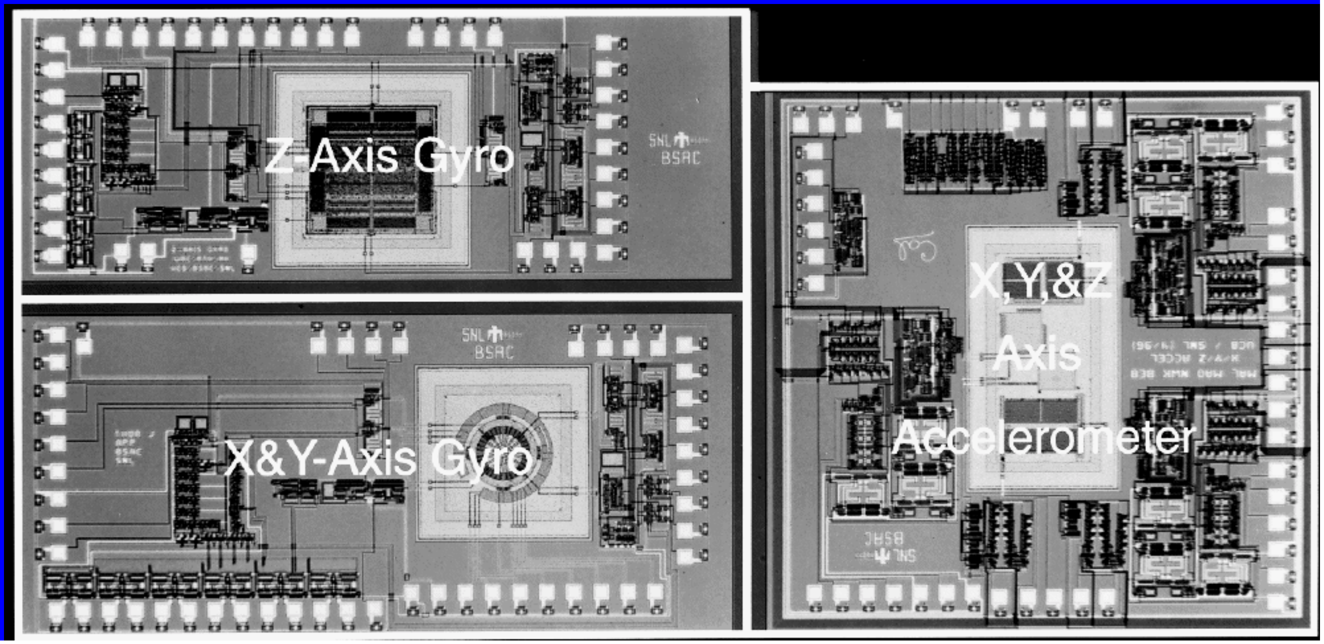
P_{total} = 50mW
P_t = 5mW
$\theta_{½}$ = 1mrad
BR = 2 Mbps

25nJ/bit!

$A_{receiver}$ = 1m^2
P_r = 10nW (-50dBm)
P_{total} = 50uW /pixel
SNR = 17 dB

3 Axis Gyro

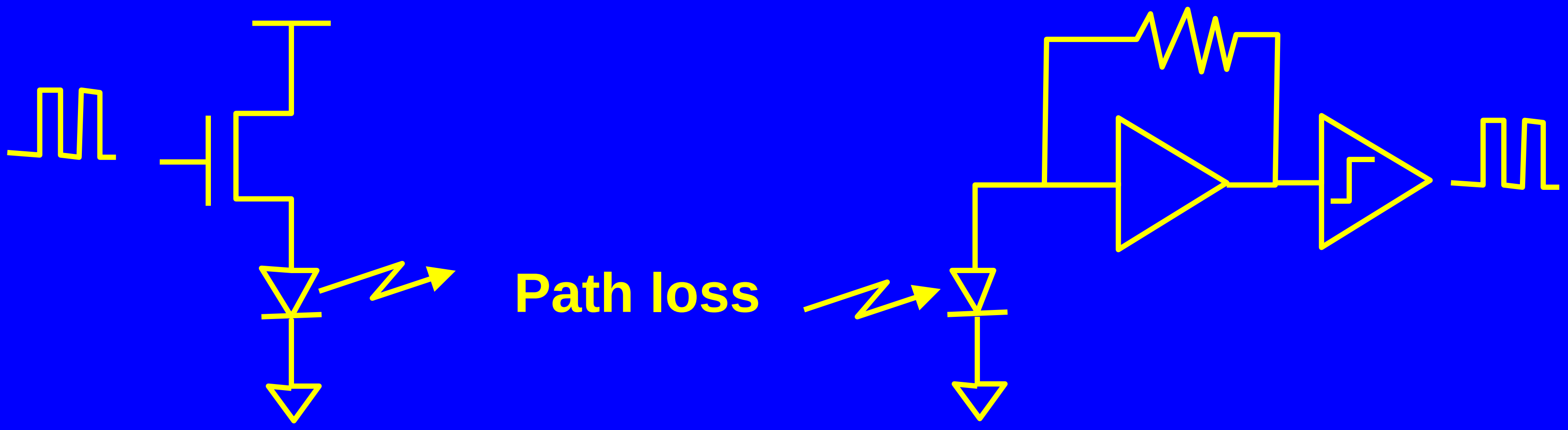
- Critical for both acquisition and maintenance stability
- Requires
  - ~10x improvement in resolution
  - ~10x decrease in power consumption



Algorithms and Software

- Acquisition
  - Binary search with variable divergence
  - 10 microsecond transitions, 10 bit “hello”s
  - <1ms @ 100m, minim
  - Gyro stabilized for long range acquisition
  - Inertial measurement for short range acquisition
- Maintenance
  - Beam dithering + gyro feedforward
  - Dynamic transmit power & pixel activation
- Ad Hoc Networking

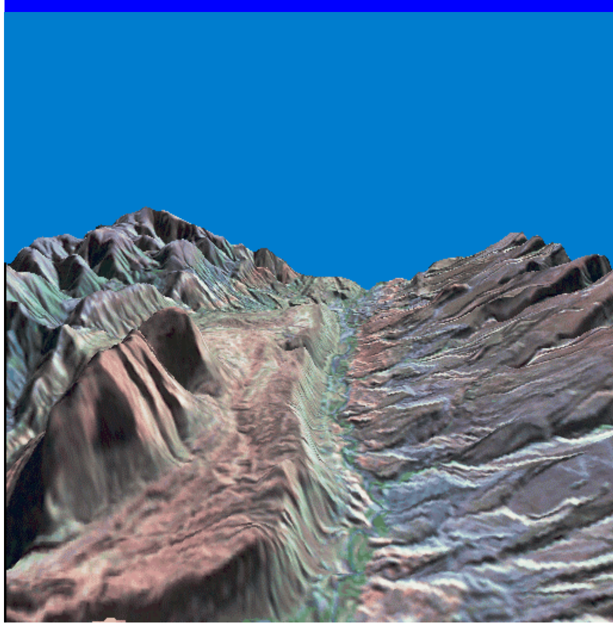
Optical Communication



Loss = (Antenna Gain) $A_{receiver}$ / $(4\pi d^2)$

Antenna Gain = $4\pi / \theta_{½}^2$

Satellite Imagery



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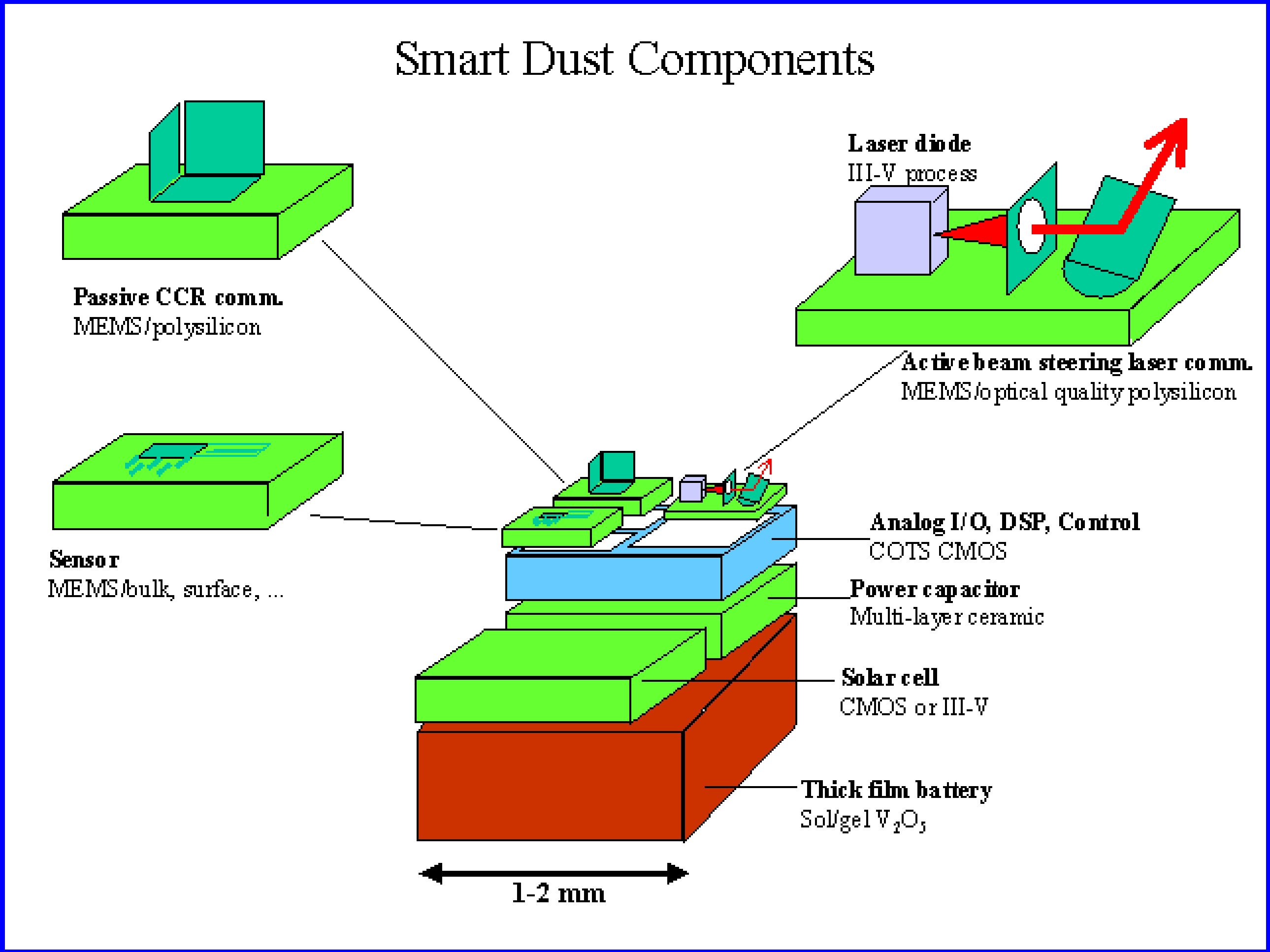
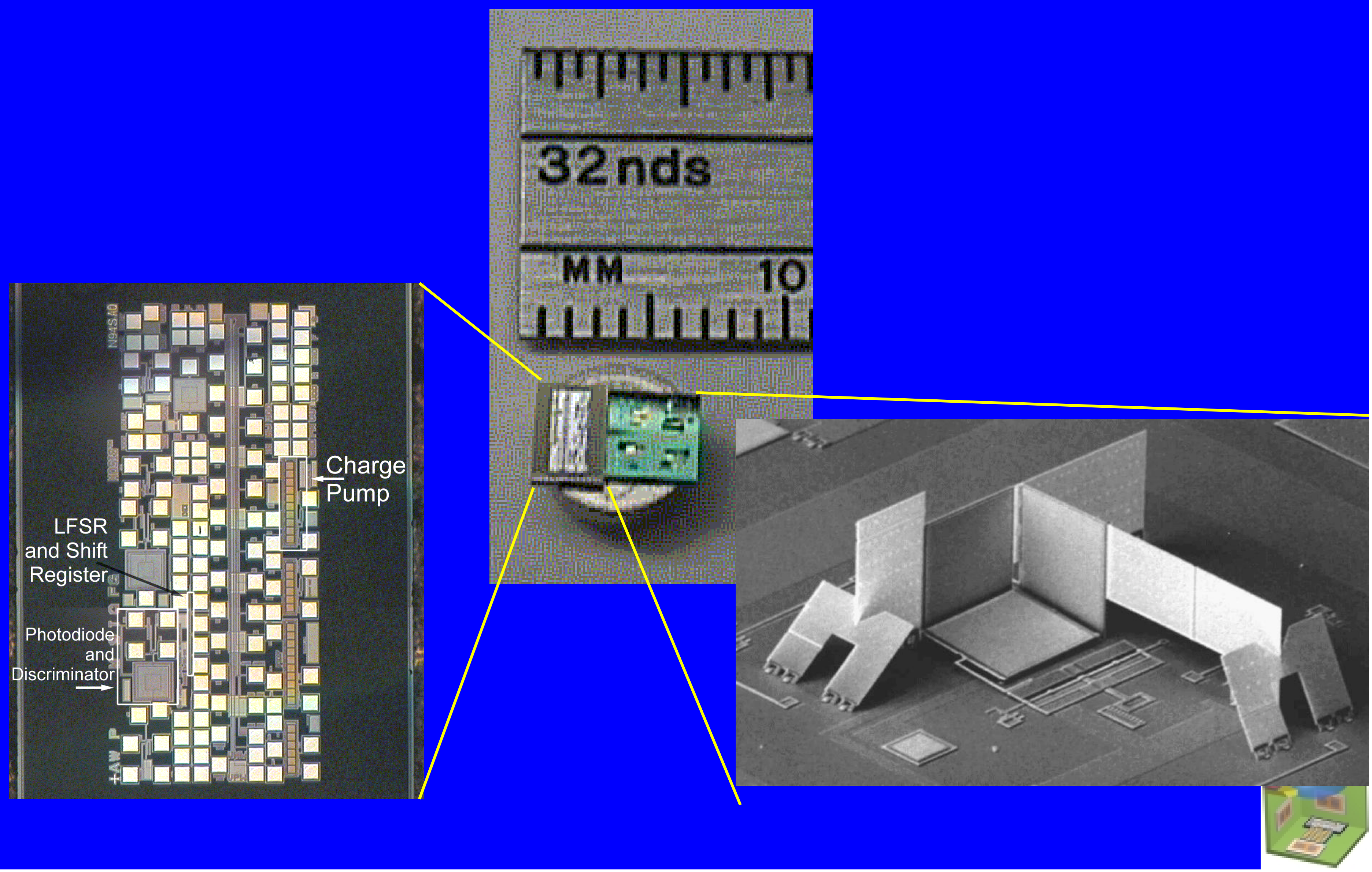
’01 Goal

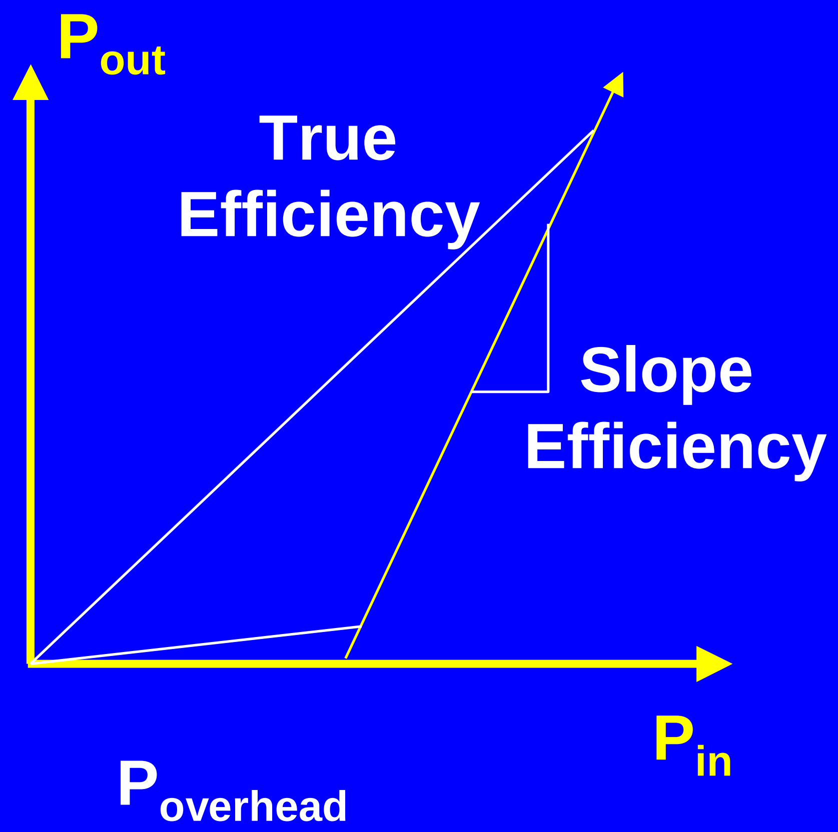


Micro Mote - First Attempt



Output Power Efficiency

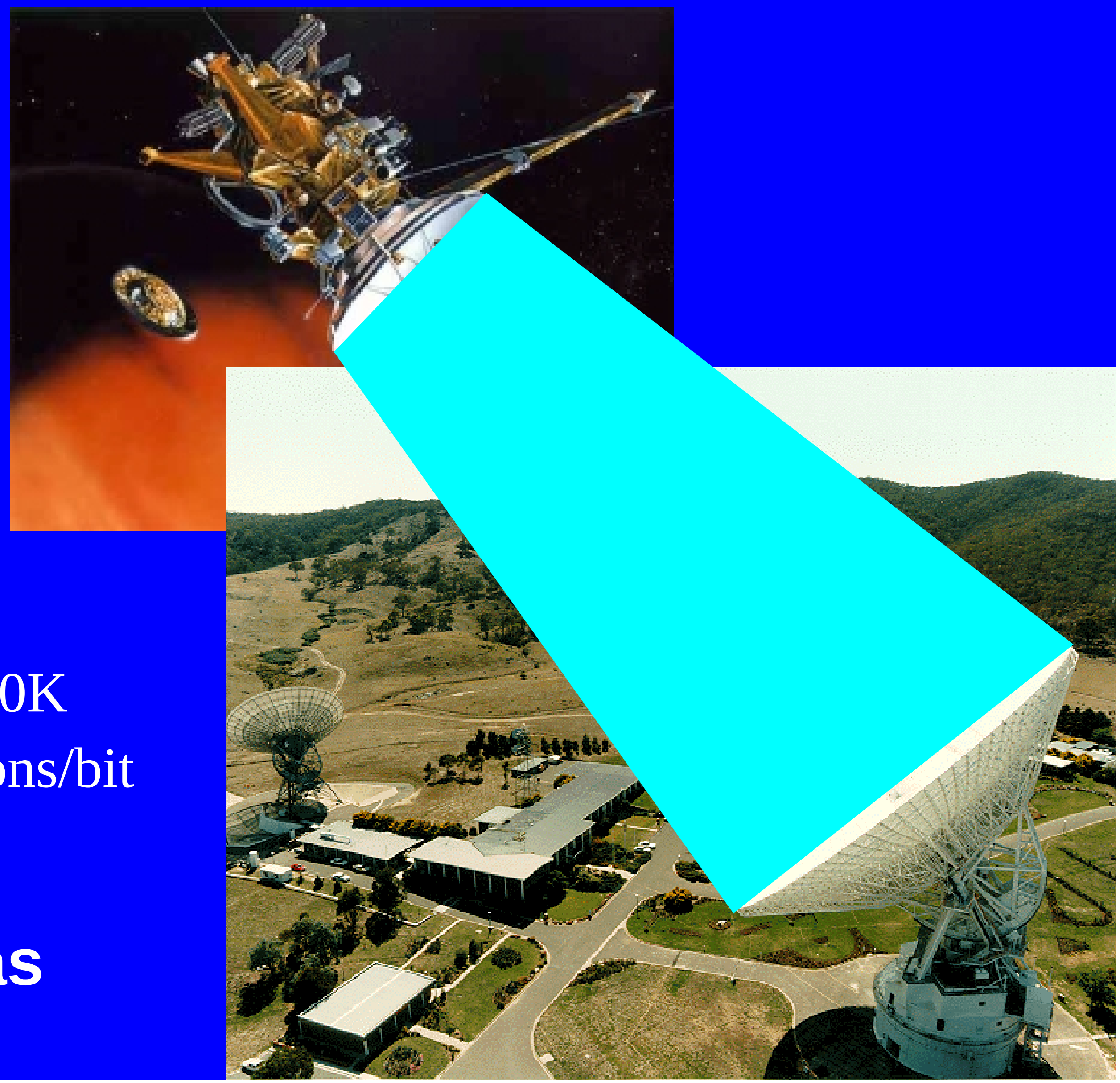
- RF
  - Slope Efficiency
    - Linear mod. ~10%
    - GMSK ~50%
  - $P_{overhead}$ = 1-100mW
- Optical
  - Slope Efficiency
    - lasers ~25%
    - LEDs ~80%
  - $P_{overhead}$ = 1uW-100mW



Limits to RF Communication

Cassini

- 8 GHz (3.5cm)
- 20 W
- 1.5×10^{9} km
- 115 kbps
- -130dbm Rx
- 10^{-21} J/bit
  - kT=4x 10^{-21} J @300K
  - ~5000 3.5cm photons/bit



Canberra

- **4m, 70m antennas**